Utility Trailer Log Loading Arch

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ABSTRACT

In recent years the popularity and availability of personal lumber mills has increased greatly. These small, affordable, and portable lumber mills have offered a way for the hobbyist and amateur sawyer to supply lumber for their personal use or begin to run a small business. The growth of this activity has created a need for a simple system that will allow logs to be collected easily and that won't break the bank of the amateur operator. This project is an answer to this by developing a system that is affordable, easy to use, and effective.

This paper will follow the design process of the utility trailer log loading arch beginning with market research. Conclusions from this research are used to determine the main design characteristics. The paper will take a thorough look at the design process and material selection, ending with manufacturing, testing, and schedule and budget summary.

Upon testing of the completed prototype, it is found that the developed system is successful in loading large logs onto a trailer in three steps, taking less than five minutes.

BACKGROUND

In recent years, the market for home lumber mills has grown substantially due to the increasing availability of portable and hobby lumber mills. These lumber mills are completely self-sufficient and do not require any support equipment, such as tractor, to operate. This allows sawyers to operate their mill even if they do not have other equipment. This leaves a problem, however, because large logs are very heavy and cumbersome to move. There still exists the problem of getting your logs to your work site, in the absence of heavy equipment. Most lumber mills offer a method of loading the log onto the cutting area, but the log must still be brought to it.

PROBLEM STATEMENT

The proposal is a loading system that is affordable, safe, and easy to use for the hobbyist and amateur sawyer. The system is intended to be designed so that it can be added onto an existing flatbed utility trailer and offer a way to load logs onto the trailer without the requirement of any other equipment. This will offer hobbyist and amateur sawyers to continue to operate their mills and collect materials without purchasing additional, expensive equipment.

RESEARCH

EXISTING PRODUCTS

Log loader trailers are already available on the market, but have several downfalls for the sub-professional user. Hydraulic units, in the form of small cranes with a grappler at the end, offer the most options in the market, but they come at a high price. Even then they fall short of the operating capacity that matches that of the mill they will be supplying. An entry level sawmill can still handle logs of significant size. Hardwoods, being very dense, come with a large weight. For example, a hickory log of 24 inches in diameter and twelve feet in length can be estimated to have a weight of 2851 lbs. (1). It would require a hydraulic loading unit of professional size to handle such a load. This has left a hole in the market for inexpensive loading systems that can still handle the necessary weight.

SURVEY SUMMARY

In an attempt to understand the needs and satisfaction of the customer, a survey was used to collect relevant data. The goal was to determine which parameters impact the systems' effectiveness the most. Twenty surveys were sent out to various woodworkers, sawyers, and enthusiasts. Six of the surveys were received back completed. The results of the survey are broken into two sections; feature importance, and current satisfaction. Table 1 contains a summary of the customer feature importance section. Table 2 contains a summary of customer satisfaction with their current log loading technology.

Features	Average
Ease of Operation	4.17
Ease of Maintenance	3.83
Durability	4.50
Transportability	3.33
Effective Load Movement	4.50

Table 1: Summary of Feature Importance

Features	Average
Ease of Operation	3.17
Ease of Maintenance	3.00
Durability	4.00
Transportability	2.50
Effective Load Movement	4.17

Table 2: Summary of Current Satisfaction

To summarize the results from the surveys, the most important features will be durability and effective load movement. All of the listed features will be taken into consideration though. According to the summary of customers' current satisfaction, their current method of loading and transporting logs is adequately durable and effective but not easily transported. This will push transportability to be an important aspect of design. From the surveys, the following conclusions were also made:

- On average, customers are willing to pay $1000-$2000 for the equipment
- Average estimated log weight customers' use is roughly 1000 lbs.
- Maximum estimated log weight customers' use is roughly 2000 lbs.

A sample of the survey sent to customers can be found in appendix A. All conclusions from the surveys are used in choosing the importance weights for the quality function deployment analysis.

CUSTOMER NEEDS

Customers require a product that is affordable, safe, easy to use, and effective in its purpose. This system is intended to be a less expensive option to other equipment. In addition to its affordability, it is imperative that the system will operate safely and effectively in order to satisfy the customer. Over the course of the system's operation, it must be easy to maintain.

PRODUCT FEATURES & ENGINEERING CHARACTERISTICS

- Easy to operate
- Moves load effectively
- Easy to maintain
- Easy to transport
- Robust/ Sturdy

In order to design a product that will satisfy the needs of the customer, these product features will be a main focus during the design stage. These features were determined based on input from the customer surveys and research that were conducted. Potential customers identified these points as key focuses in this product.

In order to design the product to be easy to operate, the steps of operation will have to be forecasted. To satisfy the demand for a system that is easy to operate, the steps of operation will be minimized and simplified. This ultimately will result in a product that works efficiently and uses the customer's time to its fullest potential. Playing part in this goal is designing the system to move the load effectively. This meaning that the load is moved in a way that results in constant progress without any hiccups in operation. Designing the product to be adequately robust will help with how effectively the load is moved. Each component will be designed so that it will handle its input forces repeatedly without failure or deformation. A design factor implemented into all calculations will ensure this. Finally, the product must be easy to transport. This simply means it can have very little effect on how the trailer it is added to will tow. Additionally, all moving components must be locked stationary for safe transportation.

DESIGN GENERATION AND CALCULATION

To start design generation, two overall concepts were considered for this system. The concepts were in regard to the method of force application into the system. A hydraulic system and a cable winch system were considered. Both have advantages and disadvantages. After reviewing these, a cable winch drive was selected based on the following conclusions:

- Lower maintenance
- Lower cost
- Lower weight
- Smaller space requirement

This design is intended for use with any flat-bed utility trailer of roughly 75 inches of inside width. Length of the trailer is not a concern for the operation or fit of the system, but does become a factor in force calculations. The calculations displayed in this overview are for a trailer of twelve feet in length. Some modification to the framing of the trailer is necessary for installation. This will be covered in the section outlining the winch mount. A 5000 lb. capacity electric cable winch was selected to supply the input force into the system. This creates another design constraint when calculating forces required to move the load. The system is designed to move a maximum load of 2000 lbs.

LIFTING ARCH

The lifting arch is the component of this system that does all of the heavy lifting. This component must be designed to span the width of the trailer, be able to pass the load beneath it, and handle the entirety of the calculated resulting force that is created by the load and input forces. Configuration of the lifting arch must facilitate adequate movement of the load onto the trailer surface.

Lifting Arch Force Calculations

The force calculations for the lifting arch reference many variables. In order to design the component to operate well in all situations, the worst-case scenario is the condition considered in all force calculations. The starting point was to consider the coefficient of friction between the log and the surface in which it's in contact with. Concrete, with a coefficient of friction with wood of 0.62, was selected as the worst case scenario (3). Using this coefficient of friction, the worst case scenario force to break static friction is calculated. To do this, an application of $\sum F = mass * acceleration$ is used where an estimated acceleration of 0.81 ft./s^2 is used and the angle of input, σ, ranges from 0 to 90 degrees measured from vertical. This estimated acceleration comes from assuming the winch reaches full line speed in one second, again intended to be a worst case scenario situation. The equation becomes:

$$F_L = \frac{M * a + \mu * W}{\sin\sigma + \mu\cos\sigma}$$

Where:

- M= mass
- a= acceleration (ft./s^2)
- μ= coefficient of friction
- W= weight, 2000 (lbs.)
- σ= input angle (degrees)

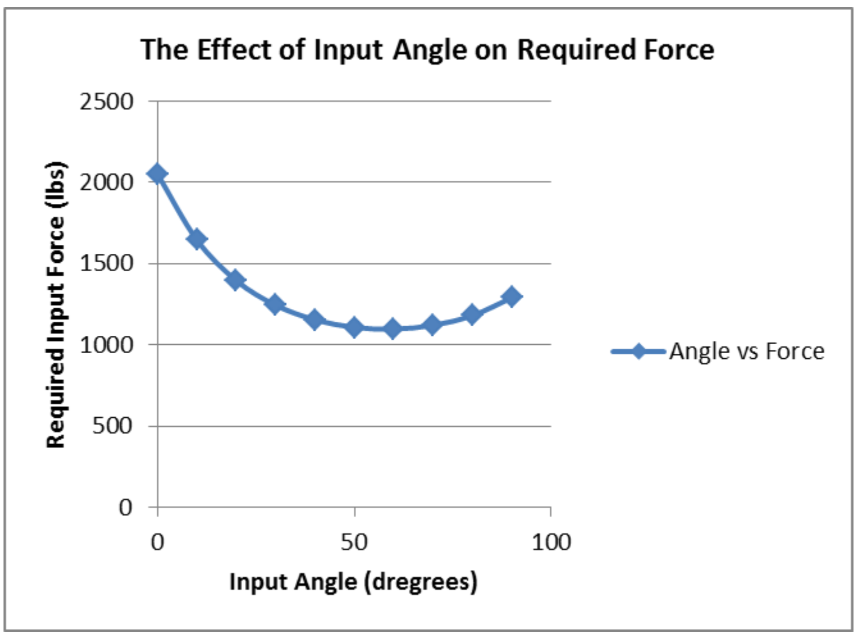

Figure 1: Effect of Input Angle of Required Force

Figure 1 shows that the force required to break static friction is affected by the angle of force input. The worst case scenario is to lift the log vertically, which in turn, eliminates the effect that friction has on the movement. For design purposes, an input angle to the load of zero degrees and a resulting load force of 2050.3 lbs. is used.

Next, the input force required from the winch to move the load in this manner is calculated. To do this, an application of $\sum M_o = I_o\alpha$ is applied where "O" is the point where the arch is connected to the trailer via the hinge plates. Some assumptions are made: the weight of the component is estimated as 200 lbs., and the moment of inertia is modeled as a uniform rod fixed at one end. The equation becomes:

$$F_{in} = \frac{I_o\alpha - AL\cos\sigma\sin\theta - AL\sin\sigma\cos\theta - W(\frac{A}{2})\sin\theta}{A(\cos\beta\sin\theta - \sin\beta\cos\theta)}$$

Where:

- A= Height of arch
- L= 2050.3 lbs., calculated above
- $I_o = \left(\frac{1}{3}\right)ML^2$
- $\alpha = \frac{a\cos(90-\beta)}{a\cos\theta}$
- $\beta = \tan^{-1}\frac{Trailer\ Length + A\sin\theta}{\cos\theta - Winch\ Height\ above\ deck}$

Using the newly calculated input force along with the load force, the reaction forces can be calculated. This is done in two components; reaction normal to the point of rotation, and reaction tangential to the point of rotation. The equations are as follows:

$$F_n = -m\omega^2 r + L\cos(\theta + \sigma) + F_{in}\cos(\beta - \theta)$$
$$F_t = m\alpha r + L\sin(\theta + \sigma) - F_{in}\sin(\beta - \theta)$$

Where

- r= Arch height/2
- L= 2050.3 lbs.
- ω= angular velocity of arch as result of winch input at top.
- All other variables are same as previous equations.

The resultant force is calculated by:

$$F_R = \sqrt{F_n^2 + F_t^2}$$

The variables of arch height, and start angle are the remaining entities under examination. Table 3 shows the effects arch height and start angle have on the calculated forces. The input forces shown in red are outside the capability of a 5000 lb. winch, so an arch height of 5ft and start angle of 55 degrees was selected as the design parameters. The resulting required input from the winch is 4144.4 lbs. This combined with the load force cause the resultant force of 4914.3 lbs. This is the force that the lifting arch must safely carry. Only the forces required to get the load moving are under consideration since the forces will drop once the acceleration period ends and the input from the winch becomes more perpendicular with the arch.

Arch length, A (ft)	5	5	5	5	6	6	6	6
Start Angle, θ (degrees)	45	50	55	60	45	50	55	60
Input Angle, β (degrees)	77.6	78.9	80.2	81.6	75.8	77.3	78.8	80.4
Height Difference (ft)	1.5	1.8	2.1	2.5	1.8	2.1	2.6	3.0
Reach (ft)	3.54	3.83	4.10	4.33	4.24	4.60	4.91	5.20
Estimated Arch Weight (lbs)	200	200	200	200	200	200	200	200
Moment of Inertia of A, Io (lb. ft^2)	51.8	51.8	51.8	51.8	74.5	74.5	74.5	74.5
Angular Acceleration of A, α (rad/s^2)	0.224	0.247	0.278	0.320	0.185	0.205	0.231	0.266
Angular Velocity of A, ω (rad/s)	0.224	0.247	0.278	0.320	0.185	0.205	0.231	0.266
Calculated Input Force, F_{in} (lbs)	2829.1	3417.4	**4144.4**	5078.7	2975.7	3598.6	4368.3	5357.4
Reaction Normal to Member, R_n (lbs)	3826.3	4301.2	4914.1	5732.9	3999.9	4508.2	5162.2	6034.1
Reaction Tangential to Member, R_t (lbs)	38.3	40.8	41.6	40.2	38.5	41.0	41.8	40.3
Magnitude of Reaction (lbs)	3826.5	4301.4	**4914.3**	5733.0	4000.1	4508.4	5162.4	6034.2
Reaction Angle (degrees)	45.6	50.5	55.5	60.4	45.6	50.5	55.5	60.4

Table 3: Calculated Forces

Lifting Arch Material Selection

The selected reaction magnitude is now used in material selection. Two features are under consideration for this; material type and geometry. Since shaped structural tubing is most commonly offered as A500 Grade B, the geometry is the main aspect in question. To select a tubing size, the estimated combined stresses in tubing sections were calculated. In the horizontal section, the combined stress is a sum of bending stress and shear stress. In the vertical sections, the combined stress is a sum of compressive stress and bending stress. The equations used to calculate the combined stress estimates use an arch centerline width of 68 inches and horizontal section length of 24 inches. Stress due to bending in the horizontal section is increased with length of the section. It is for this reason that the horizontal section is reduced to 24 inches from the overall width of the arch. The equations are as follows:

$$Max\ Bending\ Moment, M = \frac{FL}{4}$$

$$Bending\ Stress, \sigma_b = \frac{M}{S}$$

$$Compressive\ stress\ \&\ shear\ stress, \sigma_n\ \&\ \sigma_s = \frac{.5 * F}{A}$$

$$Moment\ reflected\ onto\ vertical\ section = \left(\frac{1}{2}\right)\left(\frac{FW}{4}\right)$$

Where:

- F= Reaction force, 4914 lbs.
- L= length of horizontal section, 24 inches
- S= section modulus of the tubing
- W= centerline width of arch, 68 inches.

X dimension (in)	3	3	3
Y dimension (in)	2	3	3
Wall Thickness (in)	0.25	0.125	0.25
Area (in^2)	1.97	1.3	2.44
*Yeild Strength, S_u (PSI)	46000	46000	46000
*Ultimate Strength, S_u (PSI)	58000	58000	58000
Selected Maximum Reaction Force, F (lbs)	4914	4914	4914
Maximum Expected Compressive Stress, $\sigma_{max, comp}$ (PSI)	1247.2	1890.0	1007.0
Section Modulus, S (in^3)	1.42	1.19	2.01
Arch Centerline Width (in)	68	68	68
Length of Horizontal Section (in)	24	24	24
Maiximun Bending Moment in Horizontal Section, M (in-lbs)	29484.0	29484.0	29484.0
Bending Stress in Horizontal Section, $\sigma_{max, bend}$ (PSI)	20763.4	24776.5	14668.7
Combined Stess Seen in Horizontal Section (PSI)	22010.6	26666.5	15675.6
Moment Reflected Onto Vertical Section (in-lbs)	41769	41769	41769
Bending Stress in Vertical Sections (PSI)	29414.79	35100	20780.6
Combined Stess Seen in Vertical Sections (PSI)	30662.0	36990.0	21787.6
Calculated Design Factor	1.891592	1.567991	2.662069

Table 4: Calculated Stress Values *Values for A500 Shaped Grade B Tubing

Table 4 contains all the stress analysis results for three different tubing geometries. These tubing selections were made based on their availability and affordability at local suppliers, they are very common and therefore easy to obtain. The 3 in. sq. by ¼ in. tubing yields the highest design factor of 2.66, so this tubing is selected to continue the design.

Lifting Arch Design

The design of the lifting arch was done in Solidworks using the selected tubing. To add rigidity to the component, large gussets made from 1/4" 1018 low carbon steel are added to the four major welded joints. To attach the arch to the trailer, mounting tabs made from ½" 1018 low carbon steel are added to the end of the vertical legs of the arch. These tabs will be half of the hinge that the arch will rotate on. End caps are added to the end of the vertical legs to create a surface for the mounting tabs to attach. At the top the arch, a load plate is added. This is simply a plate of ½" 1018 steel that creates the attachment points for winch input and load input. Figure 2 shows the design as modeled in Solidworks. Figure 3 shows a detail of the end cap and mounting tab configuration.

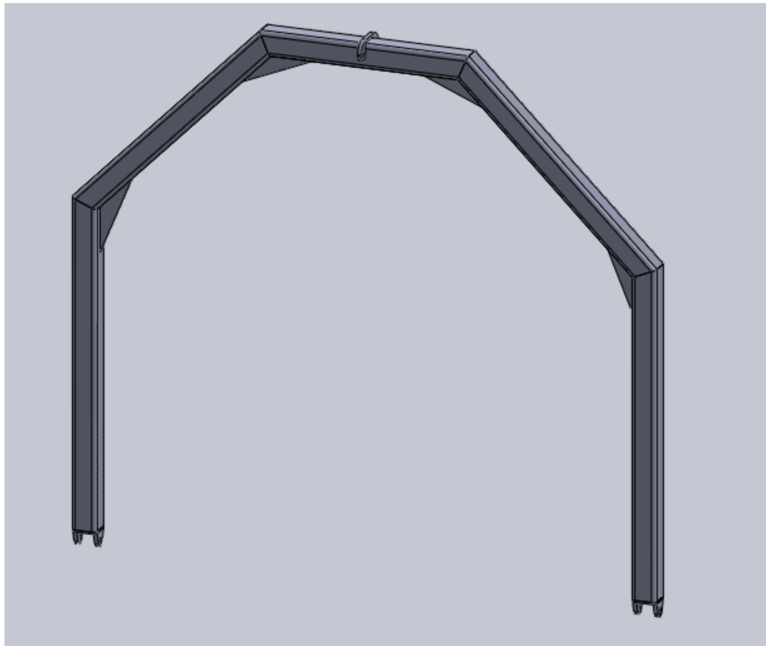

Figure 2: Lifting Arch as modeled in Solidworks

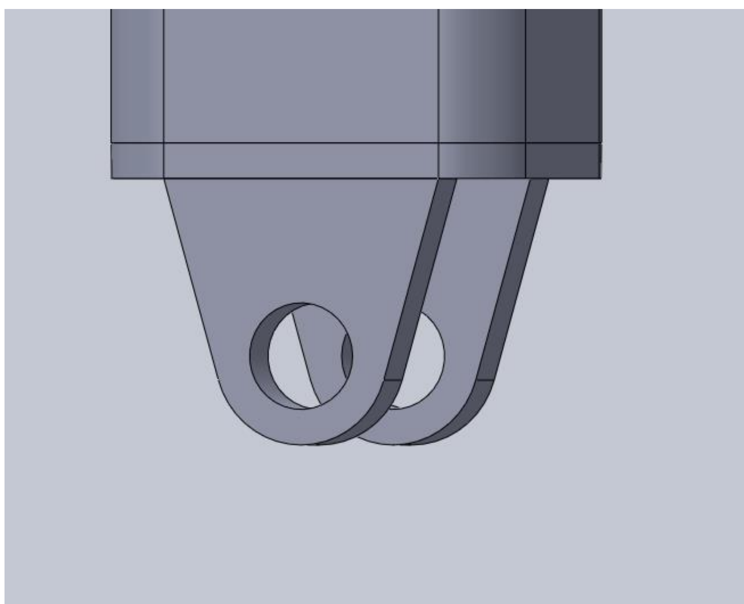

Figure 3: Detail of the end cap and mounting tab configuration.

Running an FEA simulation, shown in figure 4, yields similar results to the previously estimated stress amounts and shows the location of maximum stresses. For the analysis, the arch is by the holes of the mounting tabs and the reaction force of 4914 lbs. is applied to the flat face at the top of the load plate. Since the arch is made of two different grades of steel, the stress will be analyzed in two parts. The maximum stress experienced by the structural tubing is 20.47 ksi, shown in figure 5. This yields a design factor of 2.25 when compared to its yield strength of 46 ksi. The mounting tabs experience to maximum stress of 21.56 ksi, as shown in figure 6. This yields as design factor of 2.49 when compared to its yield strength of 53.7 ksi.

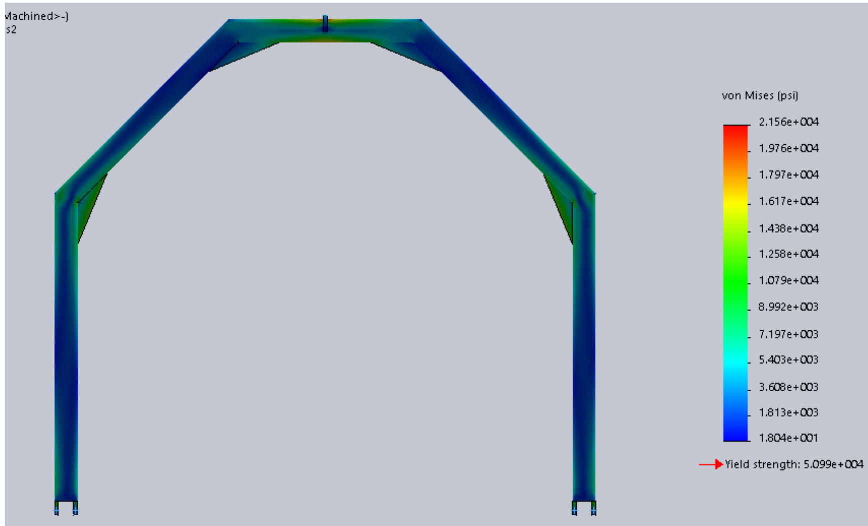

Figure 4: Results of FEA analysis

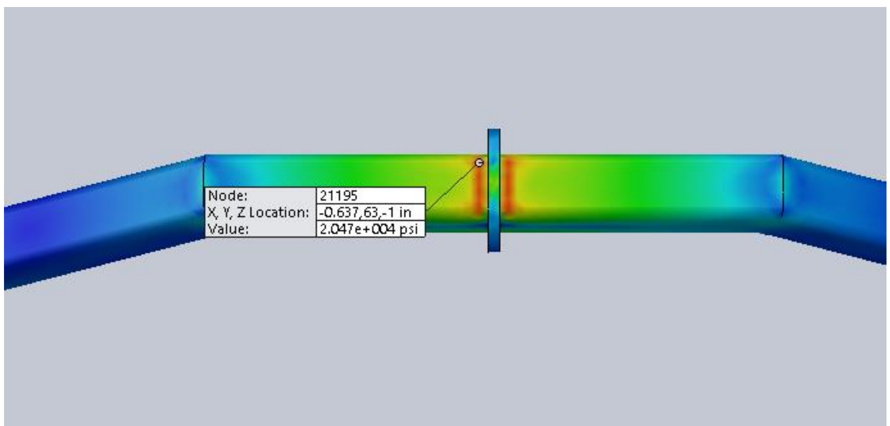

Figure 5: Maximum stress experienced by the tubing

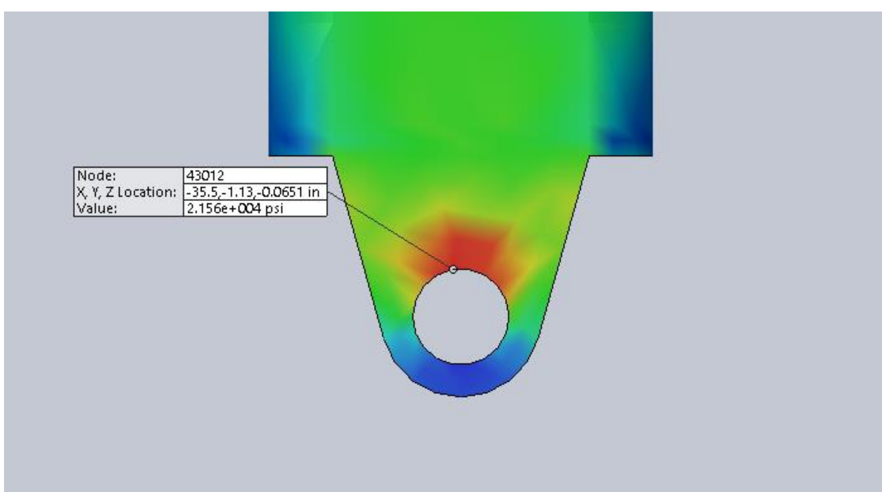

Figure 6: Maximum stress experienced by the mounting tabs

HINGE PINS

The hinge pins will connect the lifting arch to the trailer via the hinge plates. The force exerted on each pin will be modeled as half of the reaction force of 4914 lbs. applied to the arch, since there are two hinge pins. The pins must be robust enough to handle the load repeatedly, have a smooth enough surface to facilitate rotation, and hard enough to resist galling.

Hinge Pin Material Selection

Since the pins will be in contact with two mounting tabs per side, the pins will be in double shear. To calculate the shear stress seen in the pin, force applied to the pin will be divided by twice the area of the pin. The equation is as follows:

$$\tau = \frac{0.5F_r}{2A}$$

Where:

- F_r= reaction force seen by the arch, 4914 lbs.
- A= area of the pin, in^2

Table 5 shows the stress seen by the pin depending on several pin diameters

Expected Force Seen in Each, $F_r/2$ (lbs)	2457	2457
Pin Diameter (in)	0.75	0.5
Stress in Double Shear (PSI)	2781	6257

Table 5: Stress seen in the pin based on diameter

Yield strength in shear, S_{ys}, is estimated as:

$$S_{ys} = 0.5S_y$$

Where:

- S_y= is the yield strength of the material

The use of Grade 8 bolts is examined for use as this hinge pins because they offer a very high yield strength, adequate surface finish, and adequate hardness. A grade 8 bolt has yield strength of 130 ksi. Half of this value leaves yield strength in shear of 65 ksi. Table 6 shows the calculated design factor of the two examined diameters. Although both are acceptable, a ¾" diameter is chosen to reduce the bearing load and to improve the wear conditions within the joint.

Pin Diameter (in)	0.75	0.5
Yeild Strength in shear of Grade 8 Bolt(PSI)	65000	65000
Calculated Design Factor	23.37	10.39

Table 6: Design factors of the pin based on diameter

In conclusion, the hinge pins will be 3/4" grade 8 bolts. The unthreaded shank of the bolts must have a length of 3 inches so that a smooth surface in contact with all hinge surfaces. A 5 inch bolt with 2 inches of thread achieves this. Nylock nuts will be used to secure the bolts and prevent backing out.

Hinge Plates

The hinge plates are the components that will attach the lifting arch to trailer and serve as the second half of the hinge. They must be able to handle the forces applied to them from the lifting arch via the hinge pins and facilitate smooth rotation of the arch. The hinge plates will consist of a plate that will attach to the framing of the trailer by bolts and a block that will serve as the second half of the hinge. The hinge block needs to be high enough so that the arch will have adequate swing in and out of the trailer and to allow the arch to lay flat in the trailer during transportation. The design was modeled in Solidworks and is shown in figure 7.

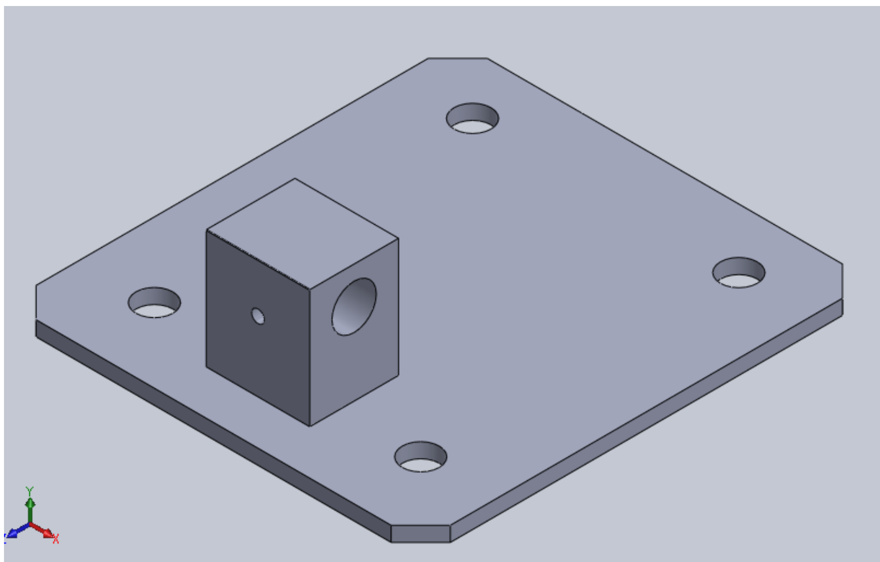

Figure 7: Hinge Plate modeled in Solidworks

Hinge Plate Material Selection

An FEA analysis was run to determine the stressed in this component. To run this analysis, the bottom side of the plate is given roller/ slider fixture and the bolt holes are fixed as they will be when installed on the trailer framing. A force of 2457 lbs. is applied to the hinge block at the start angle of 55 degrees. Figure 8 shows results of the analysis. A maximum stress of 8.318 ksi occurs where the hinge block is attached to the plate. If the hinge plate is constructed out of 1018 low carbon steel with yield strength of 53.7 ksi, the minimum design factor will be 6.46.

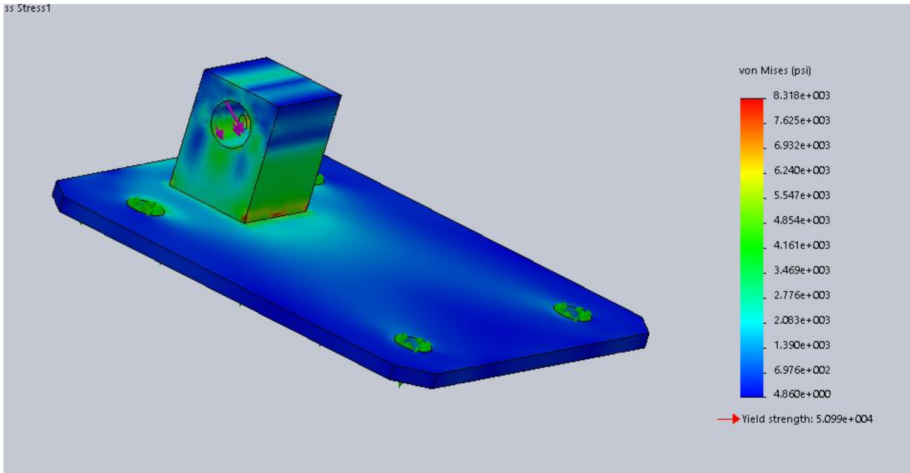

Figure 8: Hinge Plate FEA results

To determine which section of the hinge will facilitate the rotation, the bearing stress is examined. It is estimated that the rotation will happen in the section of the hinge that sees the lower bearing stress. The equation for bearing stress is as follows:

$$\sigma_b = F/A_b$$

Where:

- F= half of the reaction force seen in the arch, 2457 lbs.
- A_b= projected area of pin, D*L
- D= diameter of pin, inches
- L= length of contact, inches

Calculated bearing area in the mounting tab portion of the hinge is $0.75in.* 0.5in = 0.375in^2$ resulting in a bearing stress of 3276 psi. The bearing area in the hinge block on the hinge plate is $0.75in * 1.75in = 1.3125\ in^2$ resulting in a bearing stress of 1872 psi. Since the bearing stress is lower in the hinge block than the mounting tabs, the rotation will occur in the hinge block. To help aid smooth rotation, a grease fitting has been added to the hinge block to allow an easy way to supply grease to the joint.

WINCH MOUNT

The winch mount is the component that will attach the electric cable winch to the trailer framing. This component must facilitate the attachment of the winch, be able to carry to full force exerted by the winch during operation, and be able to attach to the tongue section of the trailer. According the force calculations, the maximum force expected to be exerted by the winch is 4144.4 lbs. The winch mount was modeled in Solidworks, shown in figure 9.

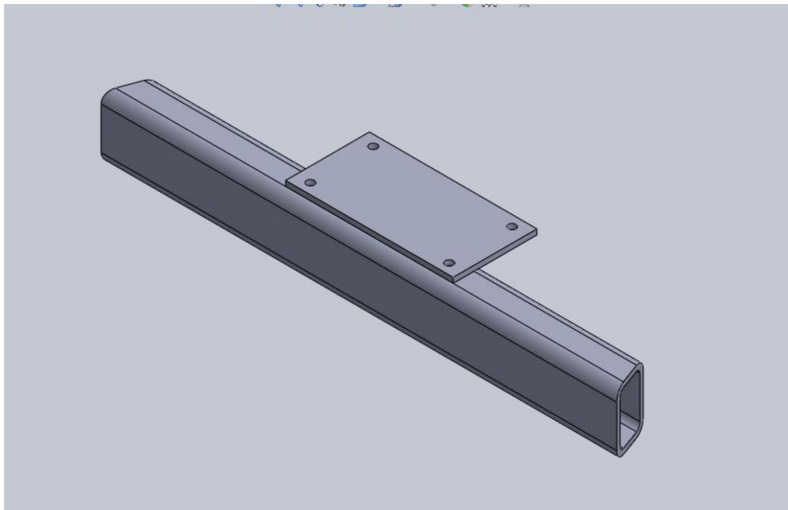

Figure 9: Winch mount modeled in Solidworks

To determine the stresses seen in this component, an FEA simulation was run in Solidworks. The results of this simulation are shown in figure 10. To run the simulation, the ends of the tube are fixed as if they are welded, as is the intended installation method. The force of 4144.4 was applied to the plate where the winch will mount at a calculated angle of 10 degrees. This is the angle that the cable will have when the lifting arch has a starting angle of 55 degrees.

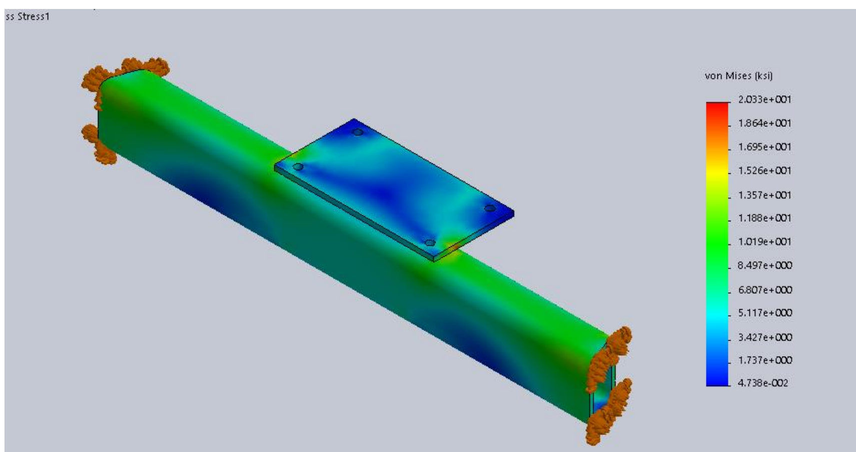

Figure 10: FEA results for the winch mount

Winch Mount Material Selection

The maximum stress result for FEA is found to be 20.33 ksi. If the tubing the sees this stress is A500 Grade B, same as the lifting arch, the yield strength is 46 ksi. This results in a design factor of 2.26. The plate that makes up the surface the winch will sit on and the gussets that brace it will be 1018 low carbon steel.

DESIGN SUMMARY

Throughout all calculations and design, the forces under consideration were a result of the worst case scenario operation situation. This comes from lifting a maximum capacity log

(2000 lbs.) directly vertically. Operating this system under this worst case scenario results in design factors being around 2.25 for several of the components. According to the customer survey, the average log weight this system will be used for is 1000 lbs. By lifting a 1000 lb. log at 20 degrees from vertical and using an estimated coefficient of friction for wood on grass of 0.4 the reaction force experienced by the lifting arch lowers to 1989 lbs., less than half of the force resulting from maximum capacity. Running the same FEA analysis for the lifting arch using this new reaction force results in a maximum stress of 8.725 ksi. Comparing this stress to the yield strength of 46 ksi, yields a higher design factor of 5.27. A similar result will be seen in all the components of the system when lifting the average expected load and rigging it in this way. Keeping the design factors on the low side allows the project remain affordable and easy to use, as required by the customers.

MANUFACTURING AND ASSEMBLY

PLAN FOR MANUFACTURE

To manufacture this design, a number of tools and equipment will be needed. The main items used will be band saw, belt sander, milling machine, drill press, grinder, and welder. Several types of welding would be acceptable for this application; I am choosing to use GMAW, or MIG, welding since it offers greater usability and less cleanup operation. The facility I will be completing the manufacture of this at is my family's private shop, located in Morrow, Ohio. I will have access to all of the tools, equipment, and consumables necessary. This will also be the location of testing.

LIFTING ARCH

The lifting arch is constructed from 3 in. square tubing with a wall thickness of .25 in. The tubing is cut to a rough length with an angle grinder so that it can then be cut more accurately on the band saw. After the final cut, each tube section is accurately sanded to the mark on a belt sander.

Figure 11: Cutting tubing to length using the band saw

Figure 12: Sanding tubing accurately to dimension

The mounting tabs and load plate are constructed from half inch plate steel and were plasma cut to general shape, without the holes which are added in a later process. The end caps and gussets are cut from ¼ in plate using a band saw and sanded into final shape.

The ends of the vertical arch sections are beveled about 1/8 inch in preparation for the end caps to be welded on. After the end caps have been welded, the sides that will have the mounting tabs are ground flat again so the center can be accurately marked. The centers of the mounting tabs are also marked and the joint beveled for welding. The center marks are lined up and the tabs are welded on. After the two mounting tabs are fully welded, a 13/16 in. hole is drilled through both at once to ensure that the holes are in line.

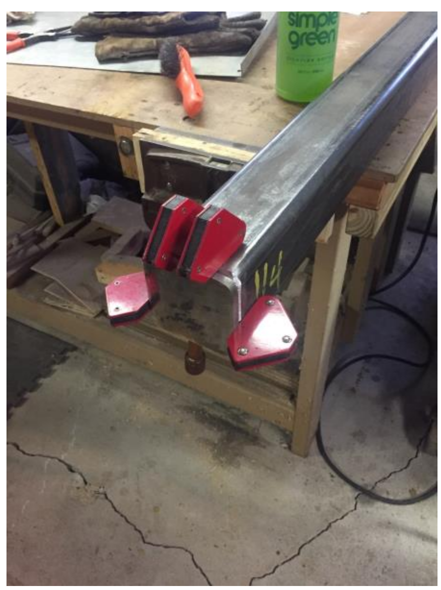

Figure 13: Fixturing the end cap for welding

Figure 14: Locating the mounting tabs for welding

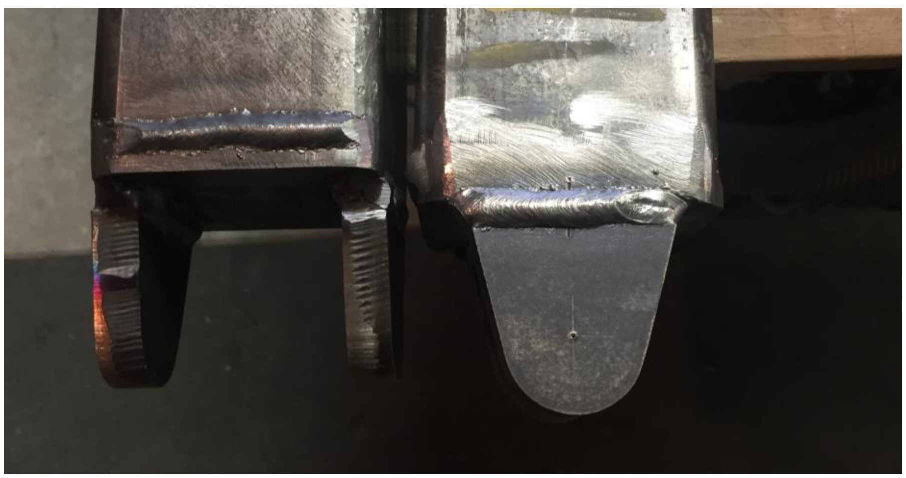

Figure 15: Mounting tabs fully welded on


Figure 16: Drilling the holes in the mounting tabs simultaneously

After the mounting tabs are completed on the vertical sections of the arch, each joint is beveled, fixture and tack welded. Once the overall width is verified, the joints are final welded together using a MIG welder. The final Step is welding on the load plate at the very top of the arch and the gussets into the internal corners of each welded joint.


Figure 17: The completed lifting arch

HINGE PLATES

The hinge plates are constructed from partially from ¼ in plate and 2.5 in square billet. The hinge blocks are cut from the billet and roughed into shape using the band saw. They are then milled to final dimension on the milling machine.

Figure 18: Hinge blocks midway through machining

After final dimension is achieved, the hinge blocks are then drilled for the ¾ in diameter hinge pins and drilled and tapped for the grease fittings.

Figure 19: Hinge blocks test fitted for hinge pin and grease fitting

Next, the plate is cut using the band saw and bolt holes are drilled using the milling machine. The blocks are beveled and welded to the plates using the MIG welder. A test of the joint is the done before the arch was fully welded together.

Figure 20: Hinge plate during drilling process

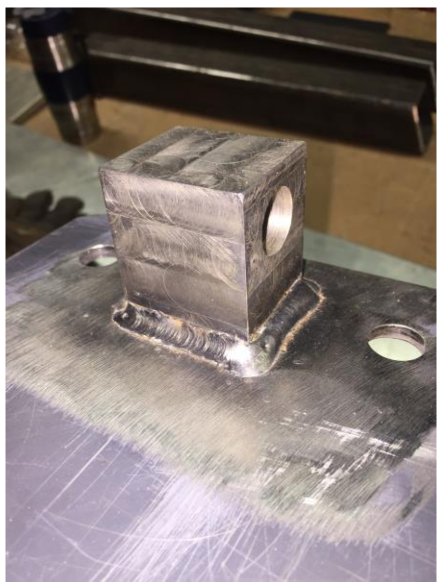

Figure 21: Hinge block welded to the plate

Figure 22: Test fitting the hinge joint

Figure 23: Installing the hinge plates to the trailer framing

The hinge plates are installed on the trailer with bolts. To get proper alignment, the arch is attached to the hinge plates and then the assembly is centered on the trailer and the hole centers are marked. The assembly is then removed for drilling and installed again once the holes are complete.

WINCH MOUNT

The winch mount is constructed from steel tubing and ¼ inch plate similarly to the lifting arch. The tubing is cut on the band saw and sanded accurately on the belt sander. Large access holes are drilled on the underside of the tube to allow for tool access to the screws that will hold the winch.

Figure 24: Drilling the access holes

The plate and gussets are cut on the band saw and welded onto the tubing using the MIG welder. The bolt holes are drilled using the milling machine after the welding is complete to ensure an accurate hole pattern. The winch mount is finally welded directly into the tongue of the trailer and the winch is bolted on.

Figure 25: Complete winch installation on the trailer

PROJECT TESTING

PLAN FOR TESTING

Upon completion of manufacture, testing will be done to verify the design and manufacture quality. The testing of this system will be rather simple. A logs weight will be estimated by roughly calculating its volume and multiplying it by the density corresponding to the species. In order to best verify the design condition, testing will be done with a log having a weight as close to 2000 lbs. as can be found. This procedure will be video recorded so that it can be displayed at a later time and place when a demonstration may not be realistic.

TEST RESULTS

The test load selected was a silver maple log that was 28 inches in diameter and 7.5 feet in length. By assuming a green density of 46 lbs/ft^3 for silver maple and estimating the logs shape as a simple cylinder, its weight is estimated to be 1,471 lbs.

The system was able to successfully and independently load this log onto the trailer in three simple steps, in under 5 minutes. No noticeable deformation of any components occurred and the electric cable winch was able to operate continuously and without issue. The steps of operation during testing are as follow:

1. With arch beginning at roughly 55 degrees from vertical and the log roughly 6 feet from the end of the trailer, attach the front of the log to the arch and draw it forward until the log movement is maxed out for this step. The step places the front end of the log on the trailer deck, leaving the rear end in contact with the ground.
2. Reset arch to roughly 55 degrees, attach log to the arch by its rear end and draw the arch forward. This step lifts the log completely onto the trailer deck.
3. Lay the arch down to rest on the top of the log, attach winch cable directly to the log and draw it forward until proper weight distribution for the trailer is achieved.

Figure 26: Test log after fully loaded

PROJECT MANAGEMENT

PROJECT SCHEDULE

A preliminary schedule is shown below. This contains a rough estimate of the project working through the design stage, manufacturing, and ending with project presentation and the Tech Expo. The table shows the actual progress of the project on the far right. The project was completed far ahead of the preliminary schedule.

		Proposed		Actual	
Task	Duration	Start	Finish	Start	Finish
Design II	15 Weeks	10/10/2016	1/27/2017	10/10/2016	12/5/2017
Determine Load Requirements	1 Week	10/10/2016	10/17/2016	10/10/2016	10/17/2016
Determine Input force, drive force, and reaction forces	2 Weeks	10/17/2016	10/31/2016	10/17/2016	10/31/2016
Design Lifting arch	2 Weeks	10/31/2016	11/14/2016	10/31/2016	11/14/2016
Design Mounts/ Hinge Plates	2 Weeks	11/14/2016	11/28/2016	11/14/2016	11/28/2016
Design Drive mount	1 Week	11/28/2016	12/5/2016	11/28/2016	12/5/2016
Design III	15 Weeks	1/9/2017	4/6/2017	12/5/2016	4/10/2017
Manufacture	12 Weeks	1/9/2017	3/31/2017	12/5/2016	1/9/2017
Test	3 Weeks	3/31/2017	4/14/2017	1/9/2017	3/16/2017
Tech Expo	4/6/2017				
Project Presentation	4/10/2017				

Table 7: Summary of the project schedule

PROJECT BUDGET

A summary of the estimated and actual budget is shown below. The project was estimated to have a cost of $926 including all items that were in question. The actual project budget was $124. The cost was kept low by using materials from personal stock wherever possible and through the donation of the 5000 lb. winch.

Classification	Item	Qty.	Cost per unit	Estimate	Actual
System Drive	Electric Winch	1	$ 200.00	$200.00	Donated
	Mounting/ Rigging Hardware		$ 25.00	$ 25.00	$ 2.37
	Plate Steel	1	$ 50.00	$ 50.00	Personal Stock
	Steel tubing	2 ft.	$ 10.00	$ 20.00	
	Battery?	1	$ 100.00	$100.00	N/A
Mounting Plates	Plate Steel	2	$ 50.00	$100.00	Personal Stock
	Steel Blocks	2	$ 15.00	$ 30.00	Personal Stock
	Bearings/bushings?	4	$ 10.00	$ 40.00	N/A
	Mounting Hardware		$ 25.00	$ 25.00	$ 8.28
Lifting Arch	Steel tubing	20 ft.	$ 10.00	$200.00	$ 85.27
	Torsion springs?	2	$ 8.00	$ 16.00	N/A
	Plate Steel	1	$ 50.00	$ 50.00	Personal Stock
	Mounting/ Rigging Hardware		$ 25.00	$ 25.00	$ 12.43
Miscellaneous	Paint		$ 20.00	$ 20.00	$ 15.68
	Consumables		$ 25.00	$ 25.00	Personal Stock
			Total:	**$926.00**	**$ 124.03**

Table 8: Summary of the project budget

WORKS CITED

1. MERCKER, David and TAYLOR, Adam. Estimating Weight of Logs and Standing Timber. [online]. [Accessed 28 September 2016]. Available from: https://extension.tennessee.edu/publications/documents/sp748.pdf

2. Wood-Mizer LT15 Sawmill. *Wood-Mizer LT15 Sawmill* [online]. 2015. [Accessed 28 September 2016]. Available from: http://woodmizer.com/store/product/index/4

3. Friction and Friction Coefficients. *The Engineering Toolbox* [online]. [Accessed 25 October 2016]. Available from: http://www.engineeringtoolbox.com/friction-coefficients-d_778.html

4. AISC 13th Edition Structural Shapes Properties Viewer - Engineers Edge. *AISC 13th Edition Structural Shapes Properties Viewer - Engineers Edge* [online]. 2016. [Accessed 6 November 2016]. Available from: http://www.engineersedge.com/materials/aisc_structural_shapes/aisc_structural_shapes_viewer.htm

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6. AISI 1018 Steel, cold drawn. *Matweb Material Property Data* [online]. [Accessed 6 December 2016]. Available from: http://www.matweb.com/search/DataSheet.aspx?MatGUID=3a9cc570fbb24d119f08db22a53e2421

APPENDIX A

CUSTOMER SURVEY

In an attempt to understand the needs and satisfaction of the customer, this survey is used to collect relevant data. The goal is to determine which parameters will impact the systems' effectiveness the most.

How important is each feature to you for the design of a loading/transportation system? Please circle the appropriate answer.
1 = low importance   5 = high importance

Ease of Operation	1 2 3 4 5 N/A
Ease of Maintenance	1 2 3 4 5 N/A
Durability	1 2 3 4 5 N/A
Transportability	1 2 3 4 5 N/A
Effectiveness of Load Movement	1 2 3 4 5 N/A

How satisfied are you with the current method of loading/transportation? Please circle the appropriate answer.
1 = very unsatisfied   5 = very satisfied

Ease of Operation	1 2 3 4 5 N/A
Ease of Maintenance	1 2 3 4 5 N/A
Durability	1 2 3 4 5 N/A
Transportability	1 2 3 4 5 N/A
Effectiveness of Load Movement	1 2 3 4 5 N/A

How much would you be willing to pay for a loading system?

$500-$1000 $1000-$2000 $2000-$3000 $3000-$4000

What is the estimated <u>average</u> log weight you work with?

100-500 lbs.   500-1000 lbs.   1000-1500 lbs.   1500-2000 lbs.   2000lbs+

What is the estimated <u>maximum</u> log weight you work with?

100-500 lbs.   500-1000 lbs.   1000-1500 lbs.   1500-2000 lbs.   2000lbs+

APPENDIX B

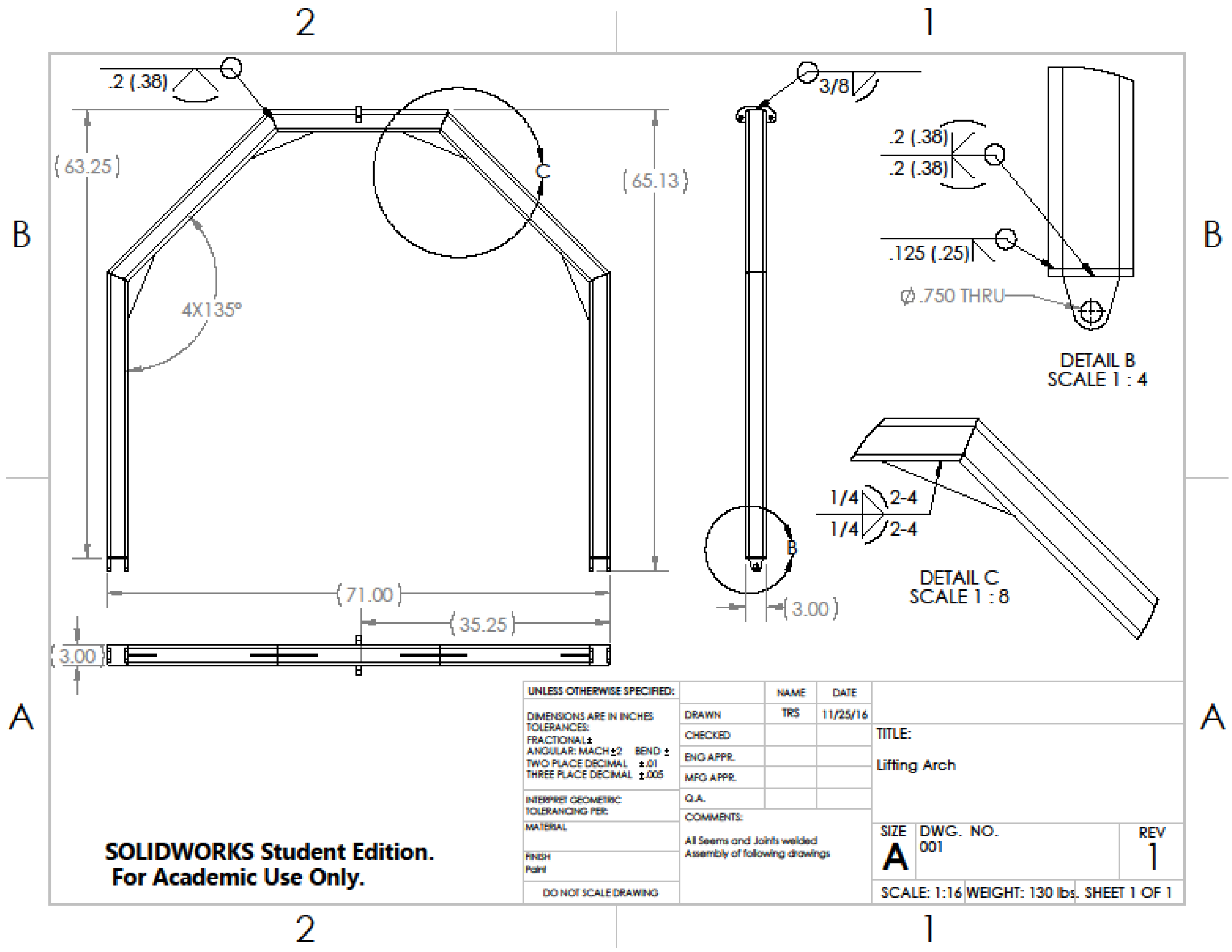
QFD

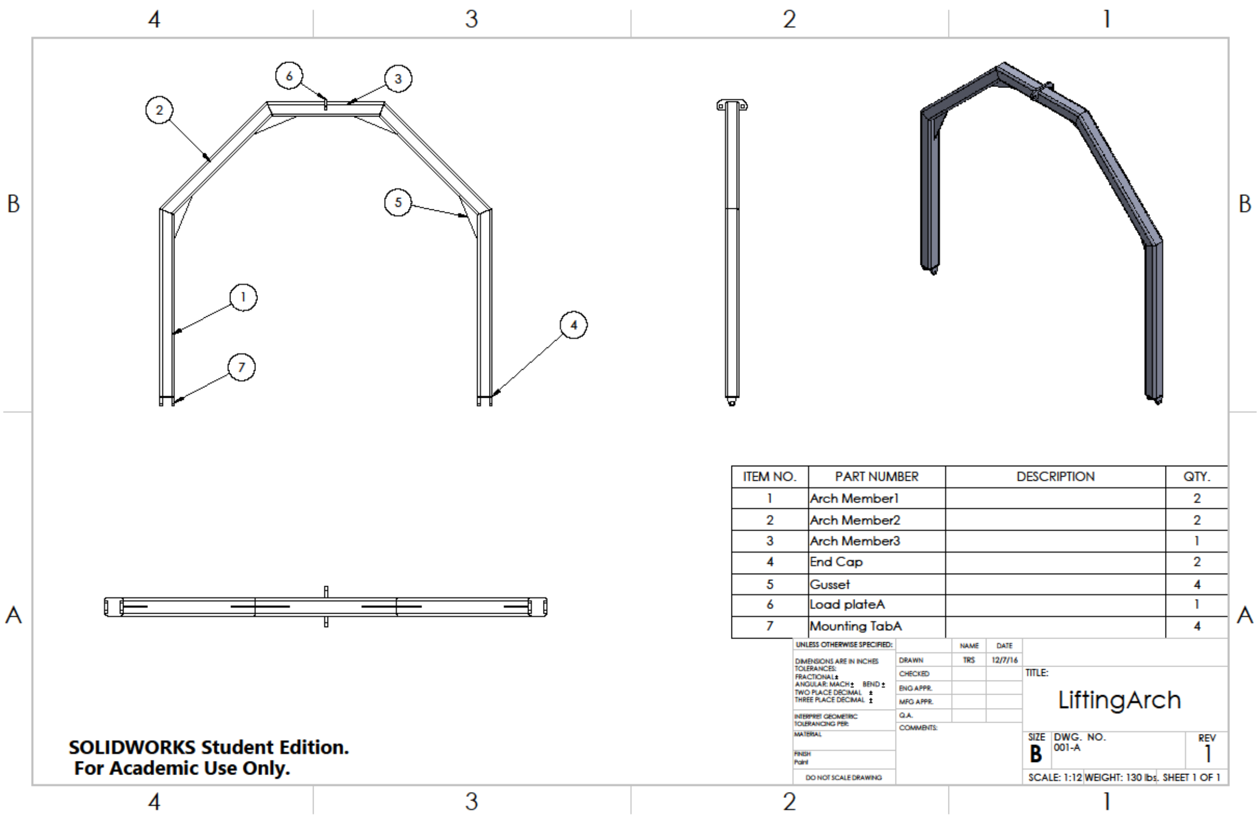
			Engineering Requirements (units)					Customer Satisfaction Rating (0.00 - 1.00)	
		Importance wt.	Steps to Operate (#)	Cost ($)	Maximum Payload (lbs)	Complex Design (low/med/hi)	Weight (low/ med / high)		
	Customer Requirements		1	2	3	4	5	CP	A
1	Affordable	0.20		9		3	3		0.2
2	Easy to Operate	0.15	9		1		3		0.9
3	Durable	0.20			3		3		0.8
4	Easy to Maintain	0.10				3			0.3
5	Moves Load Effectively	0.15	3		9		1		0.7
6	Easy to Transport	0.20			1	3	9		0.5
	Total Importance	1.00	1.80	1.80	2.30	1.5	3.6		
Performance	Current Product								
	Hydraulic Unit		1	10000	1200	high	high		
	New Product Targets		5	1500	2000	low	low		

APPENDIX C

DRAWINGS

LIFTING ARCH





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Arch Member1		2
2	Arch Member2		2
3	Arch Member3		1
4	End Cap		2
5	Gusset		4
6	Load plateA		1
7	Mounting TabA		4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
Paint
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TRS	12/7/16
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
LiftingArch

SIZE B | DWG. NO. 001-A | REV 1

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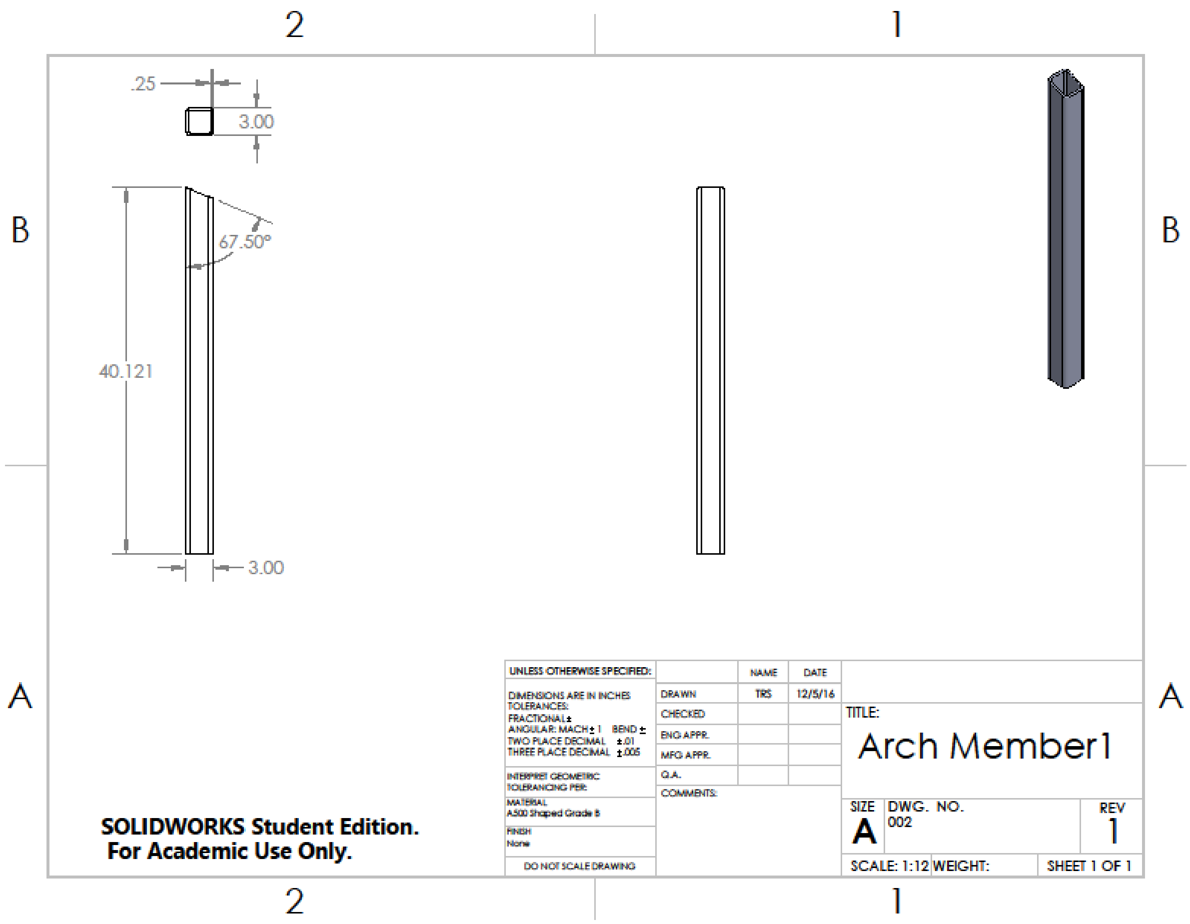
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3.00
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DIMENSIONS ARE IN INCHES
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FRACTIONAL ±
ANGULAR: MACH ± 1 BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
A500 Shaped Grade B
FINISH
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NAME
DATE
DRAWN
TRS
12/5/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
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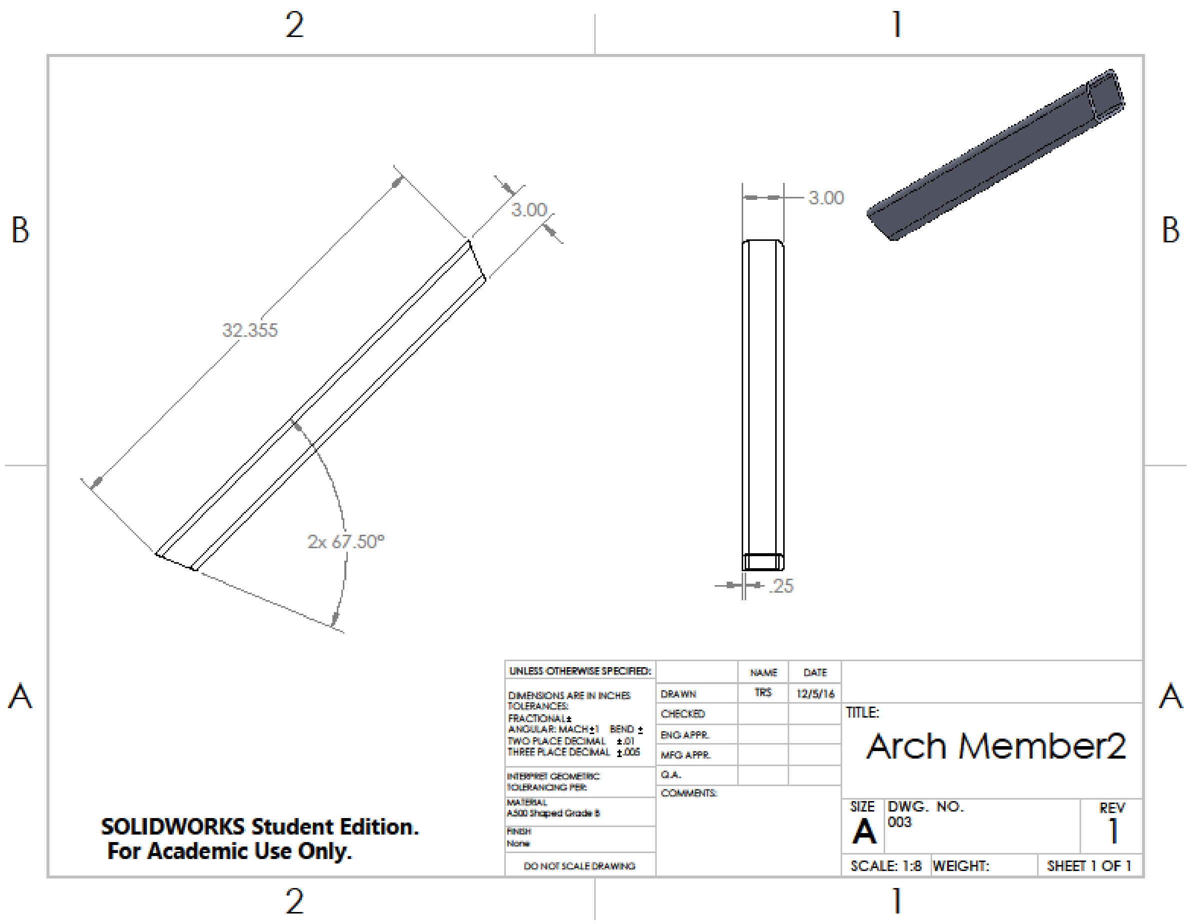
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FRACTIONAL±
ANGULAR: MACH±1 BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
A500 Shaped Grade B
FINISH
None
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DATE
DRAWN
TRS
12/5/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
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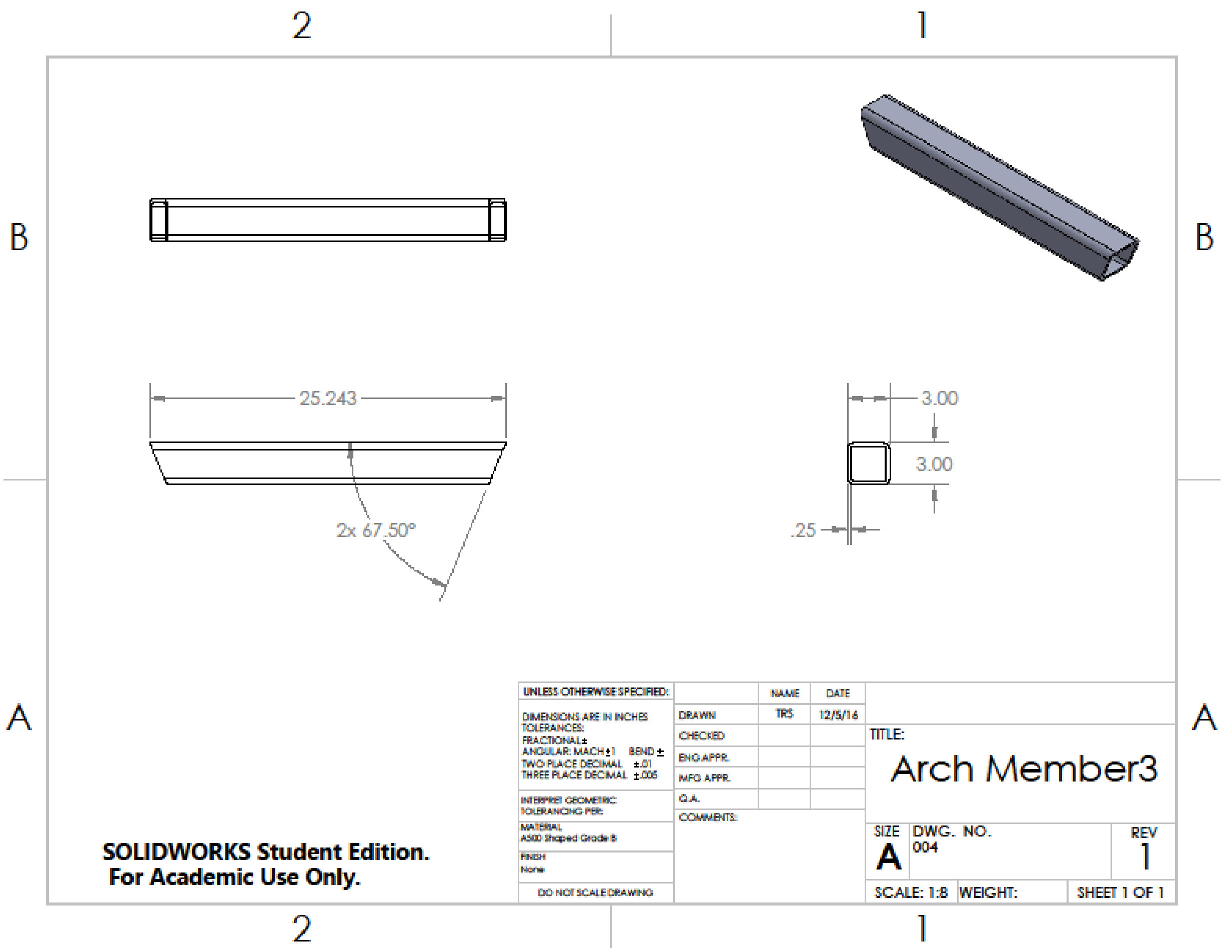
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A
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3.00
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ANGULAR: MACH±1 BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
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TRS
12/5/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
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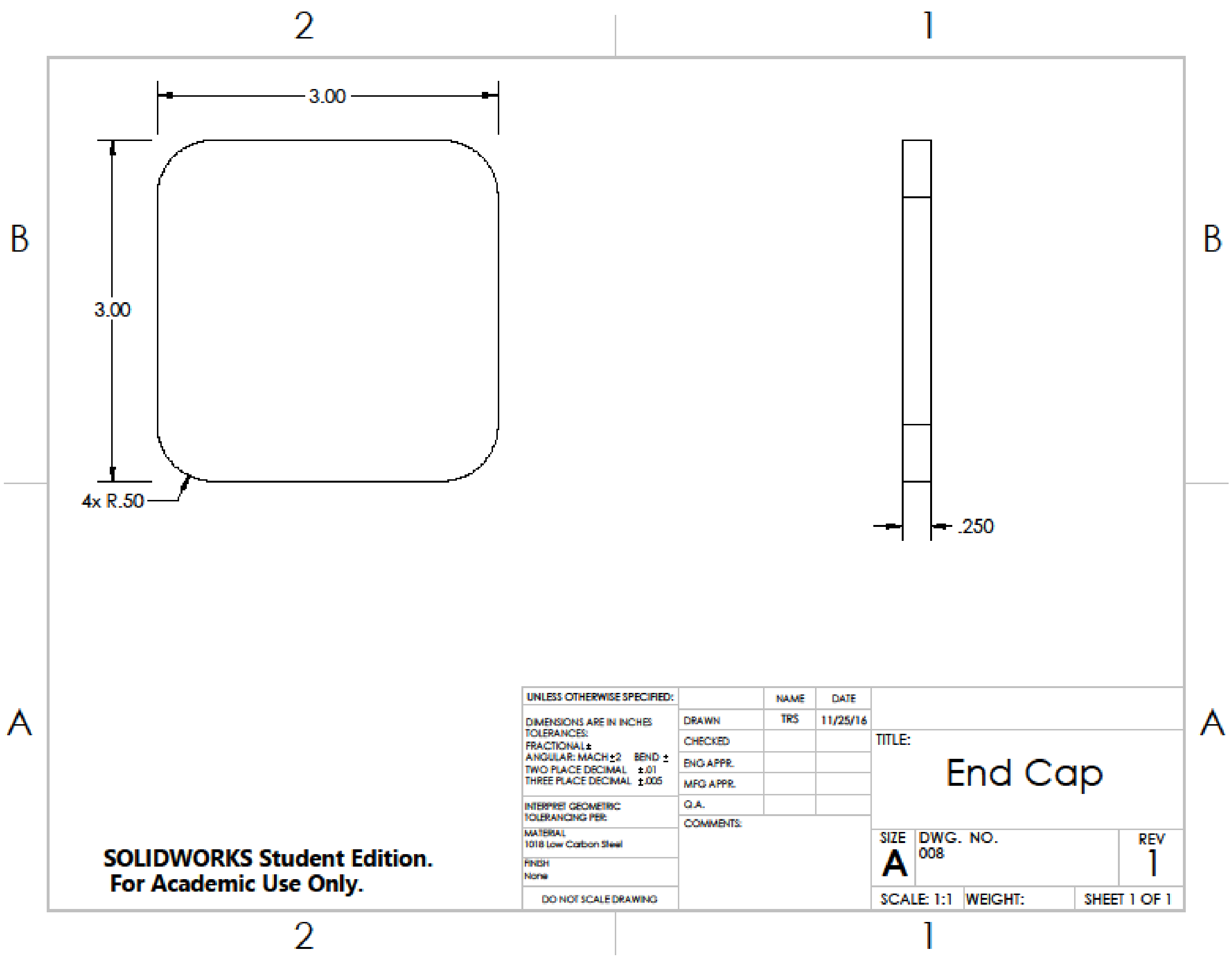
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ANGULAR: MACH±2 BEND ±
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THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
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FINISH
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NAME
DATE
DRAWN
TRS
11/25/16
CHECKED
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MFG APPR.
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COMMENTS:
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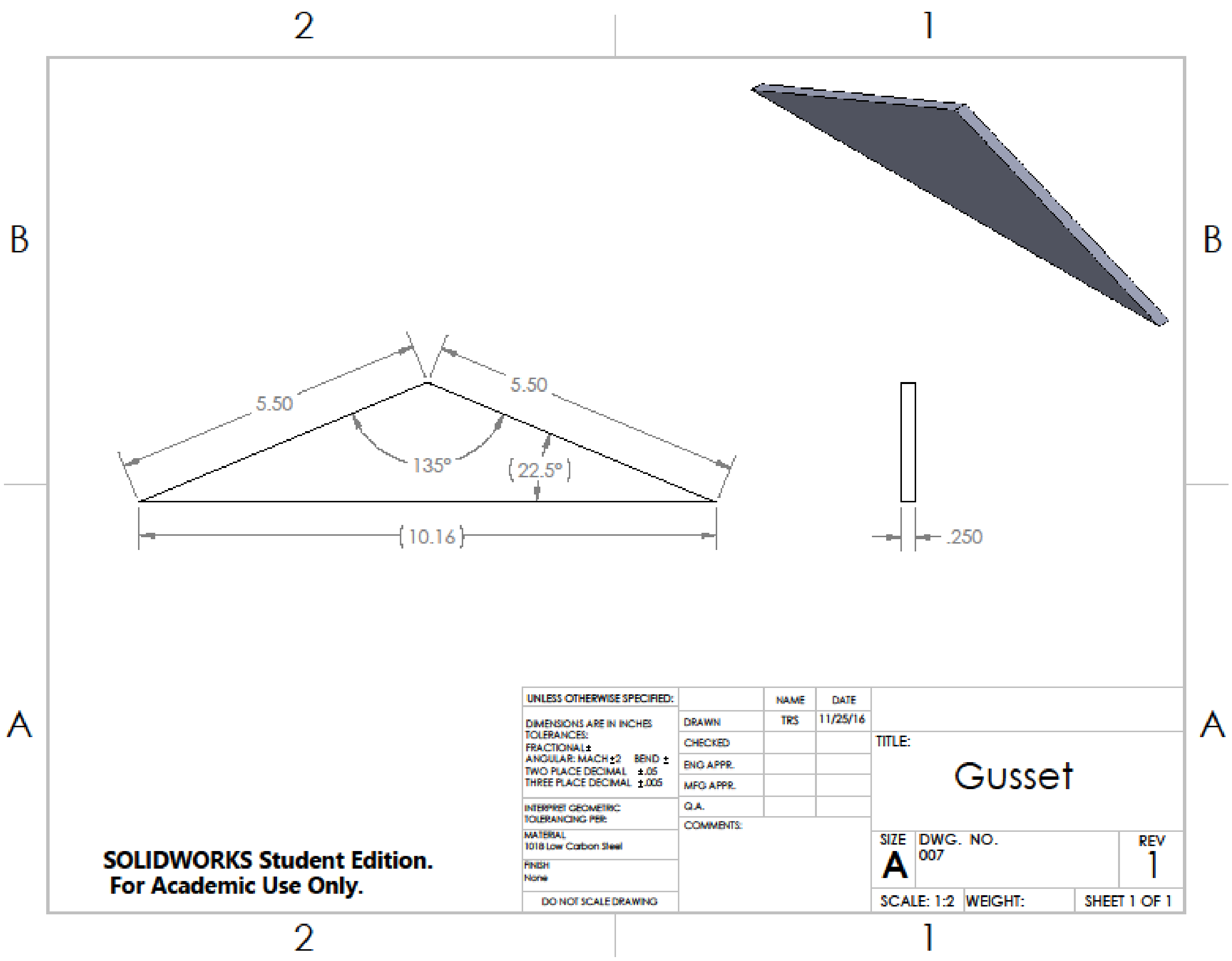
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5.50
135°
(22.5°)
(10.16)
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1018 Low Carbon Steel
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NAME
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DRAWN
TRS
11/25/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Gusset
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007
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SHEET 1 OF 1
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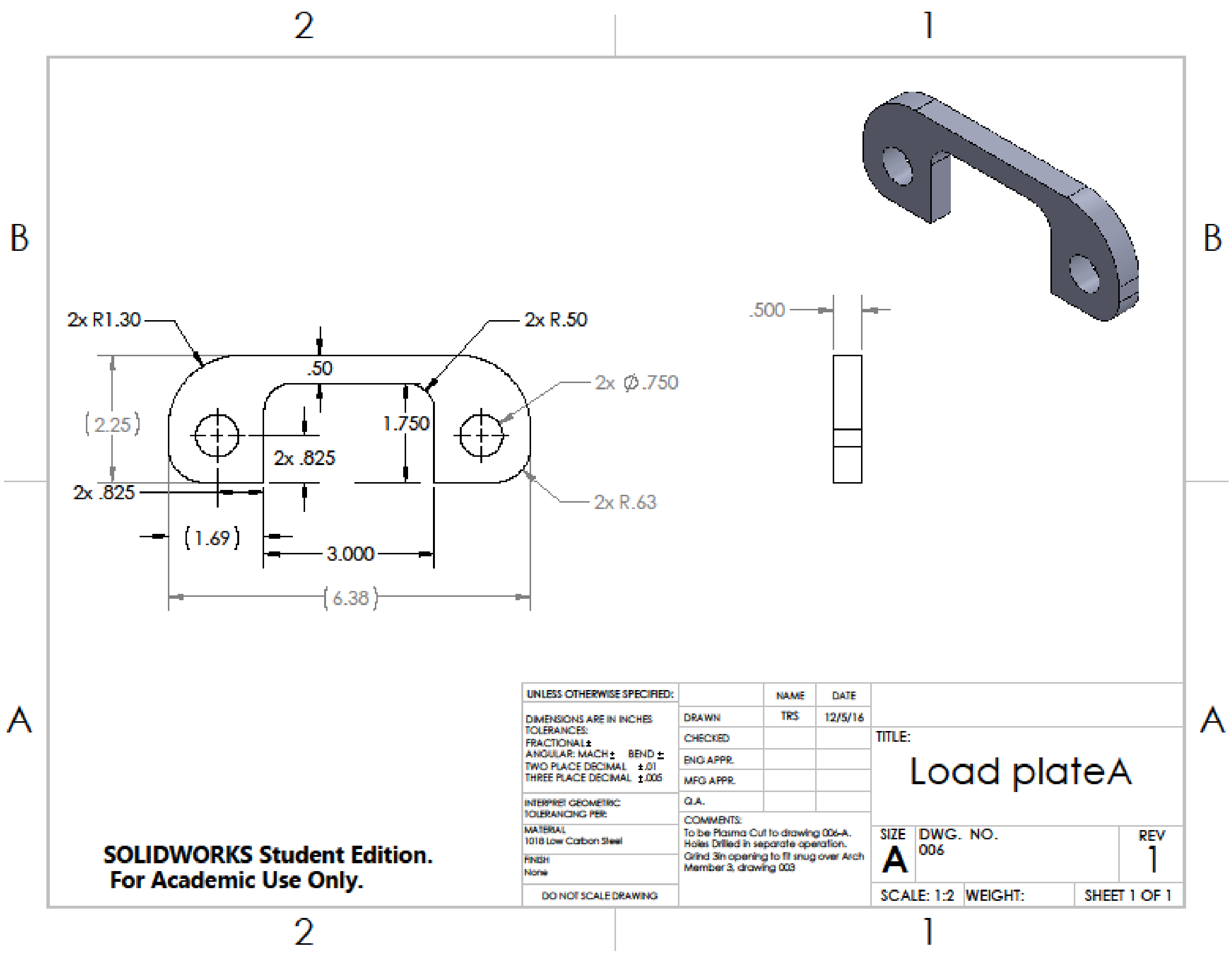
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2x .825
2x R.63
(1.69)
3.000
(6.38)
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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
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FINISH
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NAME
DATE
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CHECKED
ENG APPR.
MFG APPR.
Q.A.
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Holes Drilled in separate operation.
Grind 3in opening to fit snug over Arch Member 3, drawing 003
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WEIGHT:
SHEET 1 OF 1
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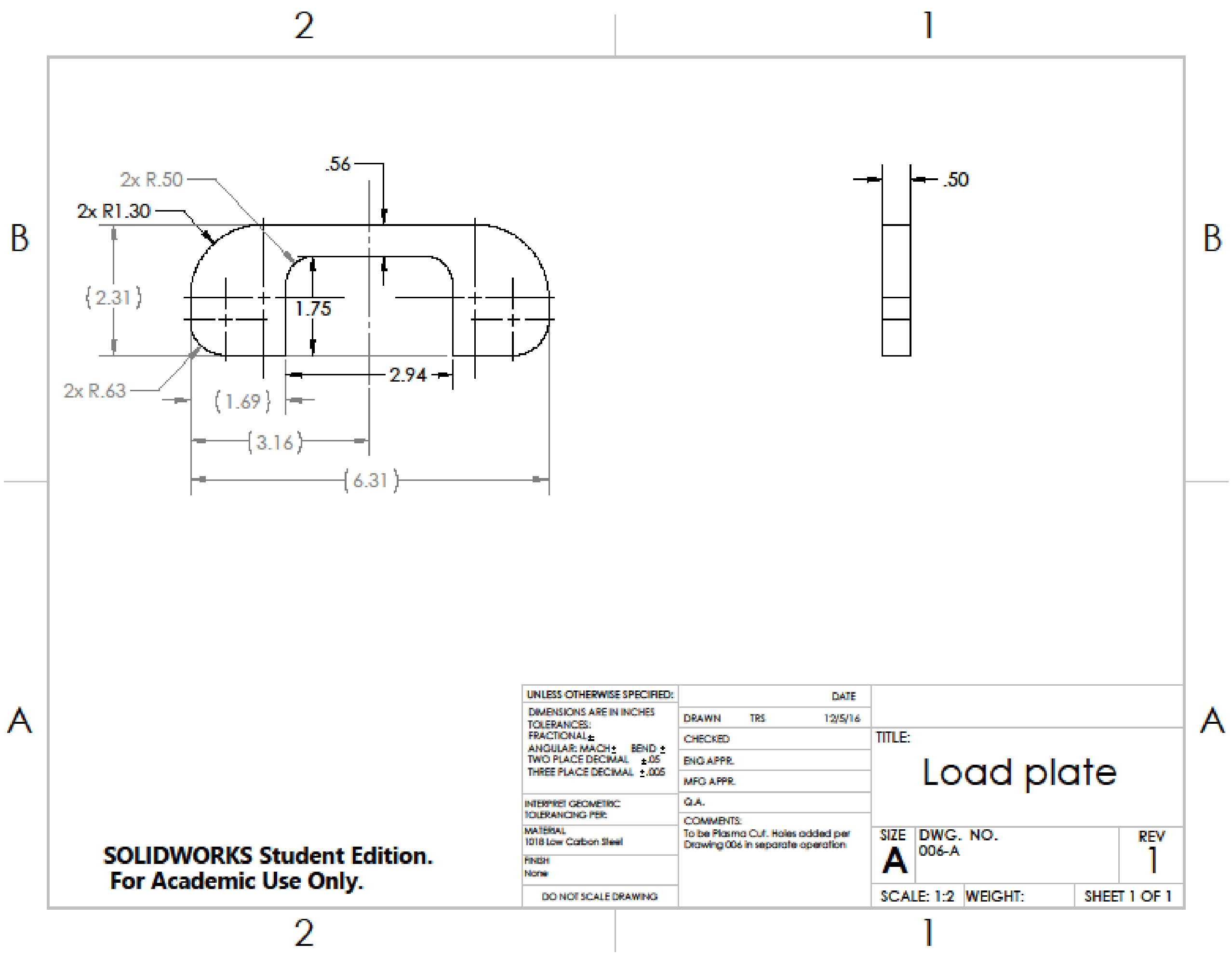

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{6.31}
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ANGULAR: MACH ± BEND ±
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THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
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FINISH
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MFG APPR.
Q.A.
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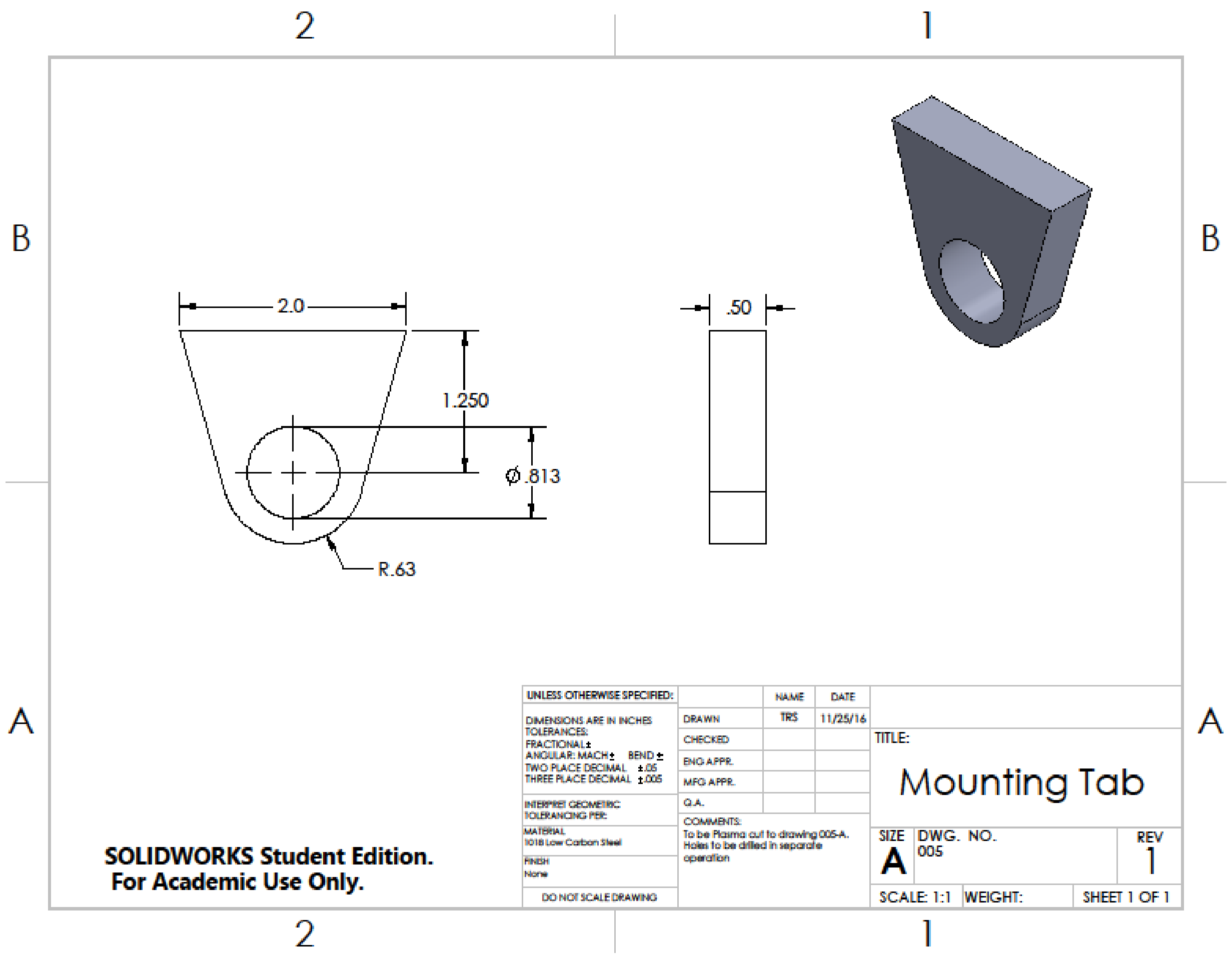
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ANGULAR: MACH ± BEND ±
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INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1018 Low Carbon Steel
FINISH
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NAME
DATE
DRAWN
TRS
11/25/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
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Mounting Tab
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005
REV
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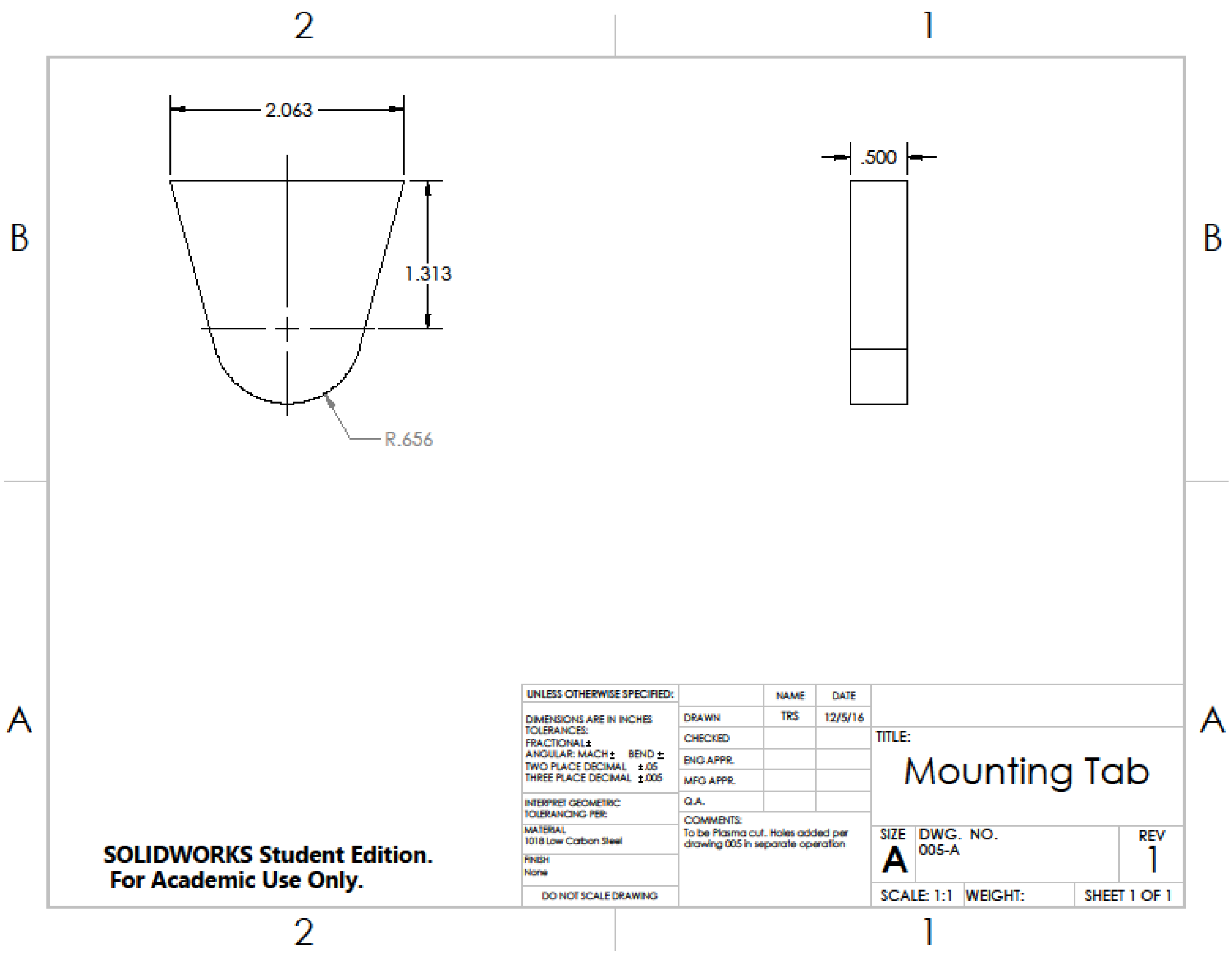
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A
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ANGULAR: MACH ± BEND ±
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INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1018 Low Carbon Steel
FINISH
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NAME
DATE
DRAWN
TRS
12/5/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
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SIZE
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DWG. NO.
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REV
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SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Student Edition.
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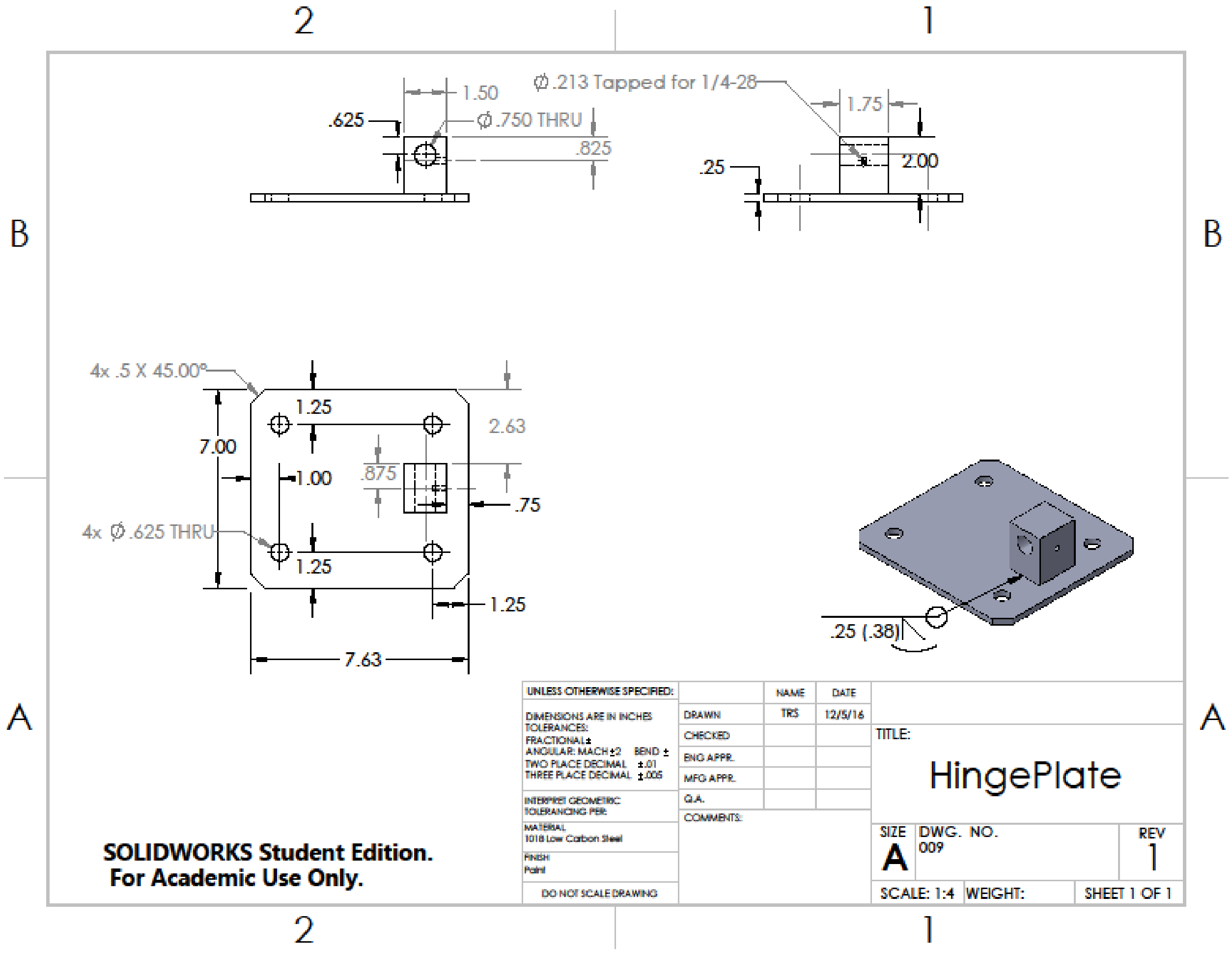
2
1

HINGE PLATE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.25
2.00
4x .5 X 45.00°
1.25
2.63
7.00
1.00
.875
.75
4x Ø.625 THRU
1.25
1.25
7.63
.25 (.38)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH ±2 BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1018 Low Carbon Steel
FINISH
Paint
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
TRS
12/5/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
HingePlate
SIZE
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SHEET 1 OF 1
SOLIDWORKS Student Edition.
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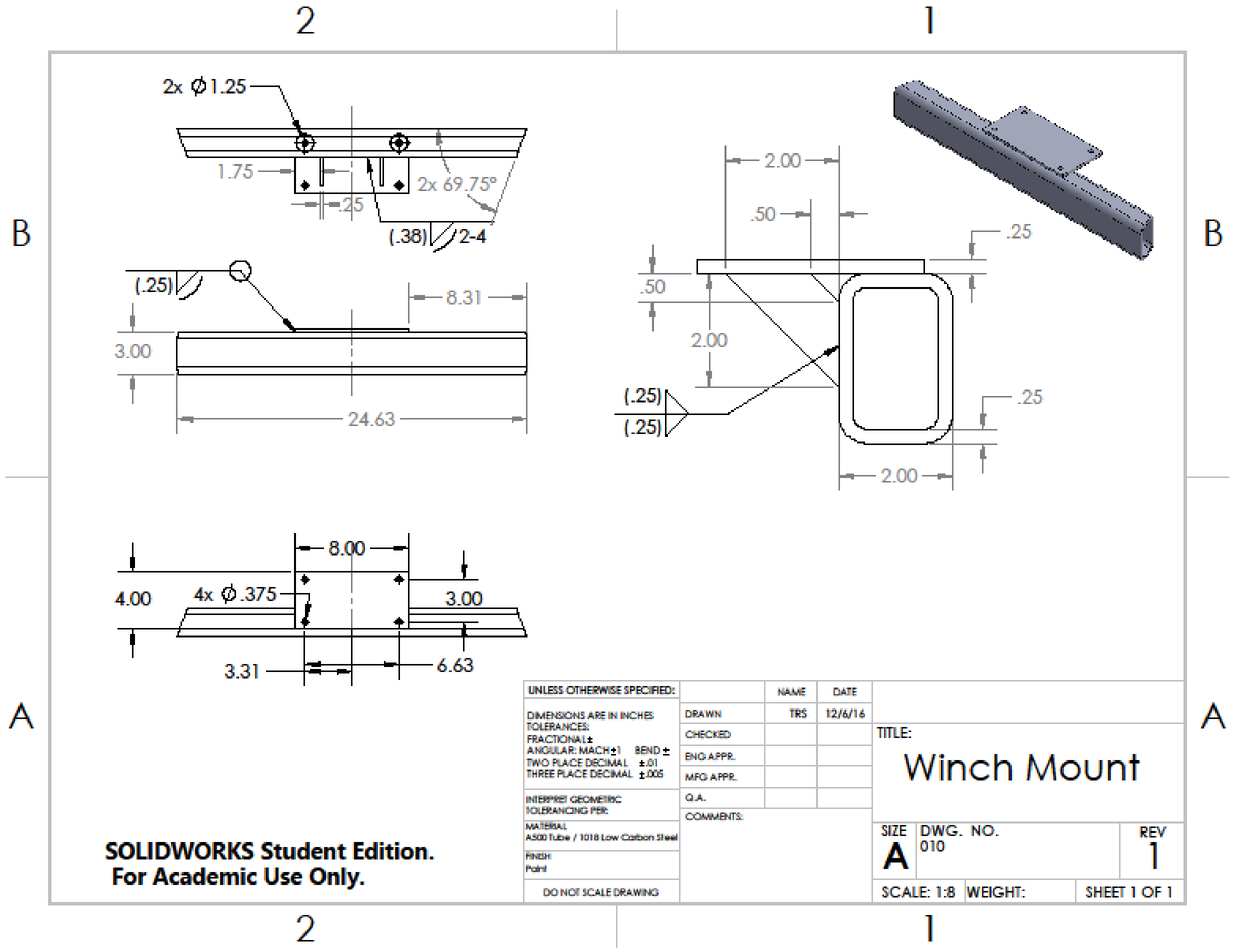
Winch Mount



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1.75
.25
2x 69.75°
(.38)
2-4
(.25)
8.31
3.00
24.63
2.00
.50
.25
.50
2.00
(.25)
(.25)
.25
2.00
8.00
4.00
4x ⌀.375
3.00
3.31
6.63
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
A500 Tube / 1018 Low Carbon Steel
FINISH
Paint
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
TRS
12/6/16
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Winch Mount
SIZE
A
DWG. NO.
010
REV
1
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1
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